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Davidite and Other Early Events in Australia's Uranium Story

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Abstract: The uranium-bearing mineral *davidite* was named for T.W. Edgeworth David. The controversy about its validity as a true mineral lasted some years. Significant studies of radioactivity and age determinations were carried out at Sydney University during the years 1904 to 1930.

Keywords: Edgeworth David, davidite, age determinations, Sydney University

INTRODUCTION

With the present interest in the use of uranium as a source of energy, it is an appropriate time to present a few snippets of early Australian research on that subject. The first scientific studies in Australia on radioactivity were carried out more than one hundred years ago. Although not himself an experimenter in this field, T.W. Edgeworth David (1858–1934), Professor of Geology at the University of Sydney between 1891 and 1924, through his encouragement and support of various students, played a significant part in the development of this research. Archibald Liversidge (1847–1927), Professor of Chemistry until 1907, also played an important role.

EDGEWORTH DAVID AND URANIUM

David and uranium are inextricably linked through the mineral davidite, named by Douglas Mawson (1882–1958) for his mentor, in 1906 (Mawson 1906). Mawson recognised the new material when he was involved in the examination of samples collected from the locality he named Radium Hill, in South Australia. The presence of carnotite (a yellow potassium uranyl vanadate), first attracted attention, as a probable decomposition product of another uranium compound. The primary substance in the orebody was black and sub-metallic. At first this main black material was suggested to be a single phase, probably a variety of ilmenite, but Mawson thought there were in fact five quite different substances, and he suspected there might be a new mineral present. Alderman (1967) makes the point that Mawson had not only a deep interest in minerals, but also an encyclopaedic knowledge. 'He displayed the hallmark of the great mineralogist–that uncanny ability to recognise almost instantly whether a mineral is unusual or "new" '.

Mawson described the 'new' substance as cuboid crystals of a black mineral with specific gravity about 4, having a brilliant lustre and glassy fracture, containing over 50% of TiO_2, a large quantity of iron and a notable amount of rare earths, uranium, vanadium and chromium. He continued 'the bright black mineral is an entirely new type, though details are not yet available for complete description. We propose to name it davidite, after Professor T.W.E. David, of Sydney University, whose personal ability, wise counsel, and enthusiasm have done so much to further the interests of the science and economic application of geology in Australasia.'

The mineral was supposed to have been chemically analysed by E.H. Rennie (1852–1927), a pupil and friend of Liversidge, (Barker & Stranks 1988), and his colleague W.T. Cooke (1877–1957) at Adelaide University, just arrived back from post-graduate studies in England. However, if their 'preliminary note' (1906) is right they did not test the correct material! They examined the material which Mawson wrote was associated with his 'new' mineral, but which was somewhat heavier and less brilliant in lustre. They pointed out that analysis was difficult, and to date incomplete, but that 'in addition to titanic and ferric oxides, which are the chief constituents, there are present ura-

nium, vanadium, cerium, and almost certainly thorium and other rare earths, traces of lime, and we believe, also chromium and traces of manganese. The quantities of vanadium and chromium, however, if present, are very small, and in the presence of uranium difficult to detect with certainty' (Rennie & Cooke 1906).

The new mineral received its first international mention in the *Mineralogical Magazine* of September 1907, where L.J. Spencer (1870–1959) listed it among newly described minerals from around the world, commenting it was 'an incompletely described mineral, possibly identical with ilmenite'. Spencer mentioned that it was named for David. However the British establishment was not too satisfied with the validity of davidite as a mineral. Thus a sample was called for and sent by Mawson to the Imperial Institute in London, to be examined by two well-accredited members of the Scientific and Technical Department of the Institute, T. Crook and G.S. Blake (Crook & Blake 1910). They were sceptical, and while accepting that the complex substance might be new, after testing they wrote 'the existence of new minerals should only be inferred as a last resource to meet difficulties which are otherwise unmanageable. In the present instance, the evidence to be handled undoubtedly presents serious difficulties, but it seems less objectionable to cover this evidence by an appeal to known minerals than by an invention of new ones, ... pending the publication of proof to the contrary, one may reasonably continue to regard "davidite" as a mineral complex ...'

At the end of the paper Crook added a footnote that Mawson, back from the Antarctic (see below), had displayed specimens of 'davidite' at a meeting of the Geological Society of London on 9 February 1910, saying it was a 'homogeneous mineral', and claiming that Crook and Blake had not seen it. Mawson gave specimens to Crook several days later, saying that 'full details of chemical analyses by Drs. Rennie and Cooke will be published shortly'. However Crook stuck to his guns, saying that he couldn't see any difference from what they had tested, writing 'the mere uniformity of appearance and continuity of a fracture-surface (Mawson believed it was a crystal face) is not sufficient to prove that the material is homogeneous; and the fragments of "davidite" which we examined show unmistakeable signs of heterogeneity' (Crook & Blake 1910).

The years from 1906 to 1910 had not been conducive to Mawson expanding on his new mineral, as David gained him a position on Shackleton's Antarctic expedition and the two of them went off to seek the South Magnetic Pole, which incidentally kept the both of them interested, at times, in mineralogy (Branagan, 2005).

It was thus some time before Mawson came back to defend his mineral. By 1911 the orebody at Radium Hill had been opened up to some degree and Mawson felt 'further reference to the association and identity of davidite is due. The davidite in its pure form is but rarely met within the lode' (Mawson 1916). He had written a reply to Crook and Blake some time in 1911 with an attendant chemical analysis, but the paper was mislaid during the period preparing for his own Antarctic expedition departure in December 1911. The paper finally saw the light in August 1916 (Mawson 1916), not long after Mawson had gone to England again to work for the Allies' war effort.

In this 1916 paper Mawson claimed that the British researchers had also, like the original 'analysis' by Rennie and Cooke (1906) tested the wrong material! Mawson's paper was accompanied by an analysis by Dr. Cooke (of Adelaide), following up on the earlier analytical work by Rennie and himself (Rennie must have been too busy to continue with the analytical work, as had been proposed, so it was left to Cooke). Cooke was sure of himself, and wrote, 'of the ferriferous and titaniferous radio-active constituents of the lode, the one referred to as davidite is the most interesting, as it is homogeneous and is a distinct species.' He gave the following analysis: TiO_2 54.3, FeO 16.0, Fe_2O_3 13.0, rare earths 8.3, V_2O_5, Cr_2O_3, and U_2O_8 4.6, MgO 0.6, CaO 1.5, PbO 1.1, CuO trace, H_2O 1.5, Total 100.9. Mawson believed himself totally vindicated.

Mawson's 1916 paper and the attendant analysis by Cooke were probably only in press

when Charles Anderson (1876–1944) of the Australian Museum, Sydney, completed his extensive, important bibliography of Australian mineralogy, so it is not surprising that Anderson (1916), relying apparently on the sceptical 1910 paper by Crook and Blake (1910), surrounded 'davidite' with inverted commas.

It was more than thirty years before Cooke's analysis was supported by other tests. There was revived interest in uranium in South Australia just as World Waw Two was ending (Mawson 1944, Mudd 2005). Of more significance for the present subject was the discovery in Mozambique in 1950 of a mineral apparently akin to, or closely related to, davidite (Bannister & Horne 1950). These researchers devoted a considerable time studying the mineral structure and testing comparable material from Radium Hill, indicating a close similarity between the samples from two such widely separated localities. The Mozambique region was shortly after looked at in considerable detail by Davidson & Bennett (1950). Bannister & Horne (1950) also pointed out an obscure reference (Golubkova 1930) indicating that a davidite-like substance had also been discovered in Russia somewhat earlier. Other sources of davidite were later discovered around the world.

Economic interest in radioactivity had remained largely centred on radium until the 1930's. In 1951 demand for uranium increased and attention turned once again to Radium Hill. Renewed exploration of the mine indicated a substantial deposit and it was realised that the significant uranium ore mineral was davidite (Nininger 1954). Almost one million tonnes of davidite was mined over the next few years at Radium Hill with an average ore grade of 1.2 kg/U_3O_8 per ton. The South Australian Geological Survey began an extensive study of uranium occurrences (Dickinson et al. 1954). Interest in uranium in NSW was also considerable between 1954 and 1961 (Mulholland & Rayner 1953, Rayner 1955, 1957).

During the South Australian Survey work detailed mineralogical examinations were carried out by the petrologist Alick Whittle (1920–1987), who made a considerable study of davidite (Whittle 1954). The work indicated the complexity of its structure and there is a hint that he suspected it was not a true mineral but a metamict phase. Rayner (1957), relying to some extent on Whittle, expanded on this matter, indicating that davidite appeared to be 'devoid of internal regular atomic arrangement', and there were 'no X-ray diffraction patterns of crystalline material'. In 1959, Whittle came out strongly that davidite was not a true mineral but a complex mixture (Whittle 1959). However the cudgel for its validity was taken up by several North American mineralogists, including J.D. Hayton (1960) who stated that davidite belonged to the group of multiple oxides which included arizonite and brannerite. He pointed out the difficulty in the analysis was because the oxidation state of the iron present was not known. Discussion continued, essentially confirming Hayton's opinion.

Today the internet offers numerous opportunities to find out about davidite, but care is needed to sort fact from fiction (or error), including misspelling of David's name, incorrect identification of Australian localities, and a considerable variety of compositions for davidite. However, the various internet sites regard it as a valid mineral, albeit with varying chemical analyses, while one site (`http://geo.oregonstate.edu/~taylore/minerals/davidite1938.htm`) shows a fine example of a crystal of davidite obtained from Radium Hill. Davidite, like David himself, has stood the test of time, and, despite some attempts to demote it, remains firmly fixed as an accepted mineral to this day.

EARLIER AUSTRALIAN WORK ON RADIOACTIVE MINERALS

There was some interest in the possibility of uranium being found in Australia as early as 1889 and even some vague reports of finds in the next couple of years (Mudd 2005). Mudd, based on Barrie (1982), mentions that G.W. Goyder (1826–1898) noted an unidentified green mineral at Rum Jungle as early as 1869, but it was not identified as a uranium mineral until 1917, when H.I. Jensen (1879–1966), a former student of David, reported uranium there.

What is probably the first specific mention of a radioactive mineral in Australia is the brief report, by G.W. Card (1865–1943) of the NSW Department of Mines, in 1894. He was referring to a small specimen of torbernite from a cobalt prospect at Carcoar, NSW (Card 1894). Edgeworth David had reported on the Carcoar prospect in 1888, when with the NSW Geological Survey. He commented on the variety of unusual minerals present, but did not find any uranium species (David 1888). Rayner (1957) in a fine review of the development of uranium work in New South Wales, refers to a report by A. Selwyn Brown (1898) on a radioactive mineral specimen said to come from Pambula on the far south coast of NSW. Rayner (1957) suggests that a more likely source of the sample was the Whipstick molybdenite deposit, some kilometres inland from the coast.

The next Australian radioactive mineral work occurred in April 1901 when Bernard F. Davis gave W.G. Woolnough (1876–1958), Demonstrator in Geology at Sydney University, and Edgeworth David a specimen he had collected in the Pilbara region of Western Australia. Woolnough identified it as gadolinite, a mineral containing a considerable percentage of rare earths. Davis took the specimen to England where he analysed it and sent back the results, which David and Woolnough presented to the Royal Society of New South Wales. The mineral was reported to have given off helium. Davis also collected two minerals 'allied to "euxenite" … essentially niobates and titanates (with tantalum) of uranium, iron and yttrium earths with the cerium earths and thorium', (Davis 1902).

Of more significance, was a joint study carried out in 1904 by Mawson and T.H. Laby (1880–1946). Mawson had made his first contact with Edgeworth David in 1899 when in the first year of his Mining and Metallurgy Engineering Course at Sydney University. Even before his graduation on 19 April 1902, with Archibald Liversidge, Professor of Chemistry approving, Mawson was appointed a Junior Demonstrator in Chemistry, David acting as a referee (Branagan & Holland 1985, Ayres 1999). At the same time Mawson was studying to obtain his B.Sc. With Mawson was Acting-Demonstrator T.H. Laby who had been recommended by his chief, F.B. Guthrie (1861–1927) at the New South Wales Department of Agriculture's laboratory. Guthrie acted as Professor during several periods of leave by Liversidge (Branagan & Holland 1985). Laby was in the unfortunate situation of being unmatriculated, but he undertook night lectures in physics, chemistry and maths.

Mawson and Laby (1904), excited by the interest in radioactivity among chemists worldwide, set out to examine 'the more common [Australian] uranium and thorium minerals' first testing them photographically and then in an electroscope, based on the design of C.T.R. Wilson. Mawson built this instrument in the University's Engineering Laboratory. They tested some twenty Australian samples and, for comparison, three from overseas (Table 1). Most were monazite-rich sands, containing thorium, but two samples, one of torbernite from Carcoar, the other euxenite from Marble Bar, were uranium-bearing and highly active. The two researchers were particularly concerned to see if radium was given off by their samples, recognising it occurred in monazite from the Pilbara and another sample from Emmaville, NSW.

As neither of the authors was a member of the Royal Society of New South Wales, David made the formal presentation of the paper to an interested audience of the Society on 5 October, 1904 (Royal Society of NSW Proceedings, 1906), when Mawson knew he had his B.Sc. and was off shortly to Adelaide University as Lecturer. Meanwhile, Laby, despite his lack of a degree, had been awarded an 1851 Exhibition to study in England (Branagan & Holland 1985). Discussion followed the talk with David, Guthrie, James Pollock (1865–1922), Professor of Physics at the University, G.H. Knibbs (1858–1929), W.M. Hamlet (1850–1931) and the authors participating. The published version gave tribute to David for his encouragement, and also to Knibbs (at that time Lecturer in Surveying, later first Commonwealth Statistician), and J.A. Schofield (1869–1934), then Acting Professor in Chemistry.

Mineral	Activity	Locality etc.
Black uranium oxide, U_2O_5	100	Taken as standard
Torbernite	highly active	Carcoar, NSW (insufficient for comparative test)
Euxenite	highly active	Marble Bar tinfields, WA (insufficient for comparative test)
Gadolinite	0.88	Cooglegong River–Greenbushes tinfield, WA
Monazite	11.30	Pilbara, WA
Fine river sand with gold, tinstone, etc	8.49	Tumberumba, NSW.
Zircon sand with monazite	0.60	Tooloon River, NSW (contains 0.45% thoria)
Concentrated beach sand	7.39	Broken Head, Richmond River, NSW.
Concentrated river sand	8.00	Tasmania
Monazite	5.47	Torrington, NSW. A large well-developed crystal
Monazite	3.25	Torrington, NSW.
Monazite	4.92	Cow Flat, Torrington, NSW (contains 0.3% thoria)
Monazite	3.11	20 miles W of Torrington (contains 1.5% thoria)
Monazite	4.46	20 miles W of Torrington (contains 1.8% thoria)
Monazite	3.31	Gulf mine, Emmaville, NSW (contains 0.6% thoria)
Monazite	3.00	as above
Monazite	3.41	as above
Monazite	3.13	as above
Monazite	2.50	as above
Monazite	4.50	Paradise Creek, Emmaville
Pitchblende	354.05	Joachimstal (for comparison)
Samarskite	47.10	Sweden (for comparison)
Thallium blende	3.75	Locality unknown. Activity may be due to the presence of other uranium minerals

Table 1. Observations on radioactivity. Total activity as determined by ionisation produced in an air-gap. Modified slightly from the original table by Mawson & Laby (1904).

Mawson's work on radioactivity, from this early beginning, moved to the mineralogical, as noted above. In fact, it was not long after Mawson arrived in Adelaide that he paid a visit to the Moonta mines (Mawson, 1944) where S. Radcliff, a chemist, was testing the ore bodies for radium minerals (Radcliff 1906). Radcliff's work on the theoretical side was being assisted mainly by W.H. Bragg (1862–1942) at Adelaide University, who presented Radcliff's results to the local Royal Society, and Mawson's visit gets no mention by Radcliff. Bragg was heavily involved, at the time, in studying radium, uranium and thorium, presenting a series of papers the same year (Bragg 1906a, 1906b, 1906c), following on his Section A Presidential address on ionisation at the Australasian Association for the Advancement of Science (Bragg 1904). Radcliff (1913) continued his interest in radium, extracting the element from Radium Hill material. In this paper Radcliff suggests that Mawson took a parcel of 30 tons of picked ore from Radium Hill to the U.K. (sending some on to the USA), presumably when he provided a large sample for Crook and Blake, but elicited no interest among potential customers for the ore.

Laby continued in a chemical vein, working during his research at the Cavendish Laboratory, Cambridge under J.J. Thomson, for which he was awarded a B.A. (Close, 1983). In 1909 Laby, just as he was about to take up a position as Professor of Physics at Victoria University College, Wellington, New Zealand, offered another paper to the Royal Society of New South Wales. David was just back from the Antarctic, but the paper was read by Guthrie, Laby's first chief. The title is somewhat enigmatic: 'On a Pitchblende probably occurring in New South Wales' (Laby 1909). The paper must have been sitting around for a few years, as Laby had carried out the analysis while at Sydney University. It essentially continued on from the joint paper he had published with Mawson in 1904. The enigma is that the sample, passed from a mineral collector, Bennett in Newcastle, NSW, to Card, and thus to Laby, was thought to have come from the New England district of that State. However Laby cast doubt on this provenance when he mentioned in a footnote that a French metallurgist, C. Poulot, saw a large parcel of what he thought was the same ore at a treatment works in Germany. It had apparently been shipped from Melbourne, suggesting that New England was an unlikely source. As far as I am aware the true source was never established.

In the meantime, chemical research on radioactivity continued at Sydney University. George J. Gray, a student of David, graduated in Science (with Geology) in 1905; he also gained an Engineering Degree and went on to practise as a geologist (Branagan 1973, Vallance 1995). In 1907 Gray described work on the radioactivity of thorium carried out at the University on specimens once again obtained through Card. Gray (1907) thanked Liversidge for his encouragement. It was the year Liversidge retired and shortly after left for England, never to return.

E.S. Simpson (1875–1939) was another of David's Engineering students, graduating with honours in 1895, and working, over the years, largely on the minerals of Western Australia. Prider (1988) believed Simpson's 'best-known scientific contributions were in connexion with the rare radioactive minerals of the Pilbara' (Simpson, 1907, 1909, 1910, 1911, 1912a, 1912b).

ANOTHER SYDNEY UNIVERSITY ASPECT OF RADIOACTIVITY

In the years following the discovery of radioactivity, one of the major interests in uranium-bearing minerals was the perceived possibility of using the rate of breakdown to measure the age of rocks bearing significant quantities of radioactive minerals, and ultimately, in measuring the age of the Earth. David saw the possibilities on this work and, following World War One, urged Mawson to take up the problem testing Australian specimens. However he had too many irons in the fire until 1944 when he mentioned that he intended to use davidite from Radium Hill for an age determination, but he never seems to have got around to it.

In the meantime, through David's encouragement, the task was taken up in Australia by Leo Cotton (1883–1963), David's successor in the Geology Chair at Sydney University. Cotton, probably with the help of Harry Gooch (ca 1884–1946), the Department's jack-of-all-trades, built the equipment to carry out the uranium/lead method of dating rocks in the early 1920's. In particular, Cotton tested some Precambrian rocks from South Australia. During this period David and Cotton were in close touch with Arthur Holmes (1890–1965) in England (David Papers, University of Sydney Archives), who had established his reputation as an authority on such matters. They were particularly interested in the methods of calculating rock ages, and Cotton did not accept Rutherford's Constant used by Holmes, arguing for a slight revision. In the end Cotton's dates differed only slightly from those of Holmes for samples from the same rock body (Cotton, 1926). Cotton first presented his results at a lecture in Adelaide, before sending off his paper to the *American Journal of Science* (Table 2). He followed up this work several years later (Cotton 1928), discussing measurements of the age of the Earth.

David mentioned the radioactive minerals in his 1932 *Explanatory Notes* (David 1932), but surprisingly or not, davidite does not get a mention, the nearest statement being 'radio-active ilmenite'. Did David suspect it wasn't a 'fair dinkum' mineral? The additional notes about these minerals in the *Geology of the Commonwealth*, which finally appeared in 1950, probably came not from David's pen, but from his former pupil, as editor, W.R. Browne (David 1950). Completed in the years immediately after the War Browne (Vol. 2, p. 315) gives davidite at Radium Hill only a minor place among the ore minerals. As mentioned above, just a few years later, when mining began, it was found to be the major uranium mineral in the ore body.

Mineral	U_3O_8	UO_3	UO_2	ThO_2	PbO	Age (Ma)[a]
Fegusonite, Coolglegong, WA		2.38		0.53	0.18	620
Mackintoshite, Wodgina, WA		Present		24.72	7.90	1475
Thorogummite, Wodgina, WA		37.33	35.6	24.46	7.78	1460
Pilbarite, Wodgina, WA		27.09	none	31.34	17.26	3840
Concentrates, Olary, SA	1.6		none		0.16	880
Carnotite, Olary, SA					1.3	240
Lodestuff[b], Olary, SA	47.8				0.40	1560
Monazite[c], Normanville, SA	2.25			10.70	0.55	1130

Table 2. The lead, uranium and thorium content (percentages) of certain Australian radioactive minerals. Modified slightly from the original table by Cotton (1926). Notes: (a) Pb/U+0.384 Th × 8000. (b) An 'intimate mixture of ilmenite, rutile and magnetite with a variable but small amount of other material' (Crook & Blake 1910). (c) R.G. Thomas, using a slightly different formula, obtained a value of 1073 Ma. For references to the original samples see Cotton (1926).

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New Aspects for Low Cost Energy by Inertial Fusion Using Petawatt Lasers

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Abstract: The prospect of generating clean, safe, virtually unlimited, universally accessible and low cost energy from nuclear fusion has cost many billions of dollars over the last fifty years. The aim is to confine the hydrogen isotopes deuterium (D) and tritium (T) and hold them in this state for a sufficient length of time at temperatures of dozens of million degrees for the nuclei to fuse into helium. The predominant method used is the confinement of the reacting plasma by magnetic fields (MCF, magnetic confinement fusion) or confinement by the inertia of a fuel pellet after extremely fast heating and compression such that much more fusion energy is produced than one needed for this ignition (ICF, intertial confinement fusion). Prospects for such processes are reviewed.

Keywords: Fusion energy, Laser, Plasma, Ion currents.

INTRODUCTION

One of the leading experts on environment problems is James Lovelock FRS, who played a key role in detecting damage to the atmosphere caused by the chlorofluorohydrocarbon emission and succeeded in their worldwide banning. He was listed by the magazine *Prospect* in 2005 as one of the hundred most influential intellectuals in the world. In an interview with Ulli Kulke for the German newspaper *Die Welt* (March 23, 2006, p. 10), Lovelock maintained that all separate observations of environmental problems have to be combined. It is for instance suggested that ocean levels may rise during the next few decades not by several meters but by up to sixty meters. These catastrophic developments may be irreversibly on the way and it might be too late to stop them. Nevertheless, they may be delayed. Under the banner '*Das ist doch grüner Unsinn*' (this definitely is green nonsense) Lovelock favours nuclear energy, and very interestingly mentions fusion energy for the future (Hora 2007, 2007a).

For the very fast ignition of controlled fusion reactions, the laser was immediately considered as the preferred tool and suggested as such by Teller (1960) and Sakharov (1961). The prospect of laser powered fusion has driven the development of very high powered lasers, including the multibillion dollar facilities at NIF and LMJ (Gerstner 2007), opening developments up to conditions of the Hawking-Unruh radiation (Hora et al. 2002a, Stait-Gardner & Castillo 2006).

As always happens when increases of orders of magnitude are achieved, new physics has been revealed and old phenomena clarified. Currently available laser pulses of petawatt ($\mathrm{PW} = 10^{15}\,\mathrm{W}$) power and picosecond ($\mathrm{ps} = 10^{-12}\,\mathrm{s}$) duration permit new schemes for fast ignition. A basically new effect based on drastically anomalous measurements (Zhang et al. 1998, Badziak et al. 1999) was explained by a skin layer theory (Hora et al. 2002, Hora 2004, 2005) in combination with much earlier computations in Australia. This effect may be used for igniting virtually uncompressed solid DT fuel by PW-ps laser pulses to ignite a very high gain controlled fusion reaction wave, which, if confirmed by further research, may lead to very low cost fusion power stations.

This controlled ignition of weakly compressed DT fuel follows a scheme of Nuckolls & Wood (2002) where PW-ps laser pulses generate ultra-intense relativistic electron beams.

The new effect led to measurements of space charge neutral D-T-ion beam current densities exceeding $10^{11}\,\mathrm{A\,cm^{-2}}$, through which ion beams instead of the electron beams of Nuckolls et al. (2002) may lead to low cost, controlled ignition of fusion.

THE SOLUTION OF NUCKOLLS & WOOD (2002)

Nuckolls (2005) suggested in 1960 that laser pulses might be used to ignite solid or lightly compressed DT directly. This can be seen from the fact that a $10^{17}\,\mathrm{W\,cm^{-2}}$ laser intensity is comparable with 11 million degree (keV) Planck radiation. This ignition has not yet been achieved, as Kidder (2005) has critically remarked. However, with the advent of PW-ps laser pulses, the chance of success has been greatly improved. Nuckolls & Wood (2002) modified the fast igniter scheme (Tabak et al. 1994) so that they produce an intense 5 MeV electron beam such that an ignition of virtually uncompressed and large amounts of DT may result in 100 MeV fusion energy produced by a 10 kJ laser pulse of ps duration.

The electron beams have to be produced by irradiation of the 10 kJ-ps laser pulse onto a plasma at pre-compression to more than 1000 times solid state density. Examples for ignition of DT are given for 10 times the solid state with the remark that for lower densities, even better conditions will be expected. This is all within a controlled energy generation and clearly different from an uncontrolled reaction. The close borderlines between controlled energy production and the uncontrolled case should not be used to bedevil laser fusion, as it was openly done by Tran (2004). Reporting on fusion energy to the UN-World Energy Conference in Sydney, he excluded laser fusion and reported only on the International Thermonuclear Experimental Reactor (ITER) using magnetic confinement fusion (MCF). Other objections to inertial fusion energy (IFE) are discussed elsewhere (Hora et al. 2005, 2007, 2007a).

To properly assess the position of ITER, the following facts have to be taken into account. This project, with funding of more than $16 billion, is scheduled to come to fruition in 2016 and the gain is still rather modest: a 500 MW electricity input should produce 500 MW fusion power during 500 seconds such that after conversion at 30 % efficiency in an electric generator, a gain of 0.3 may result (Tran 2004). The best measurement concerning magnetic confinement fusion (Keilhacker 1999) was with the JET (Joint European Torus), when a magnetically confined plasma torus during 2 seconds produced 16 MW of fusion power by irradiation of 21 MW neutral beam power and 3 MW heating by electromagnetic radiation. To this fusion gain of 0.66, one had to ignore the 100 MW of electricity which was needed to run the torus. If one takes the operation of JET into account, the gain of fusion energy is 0.129 and with 30 % conversion to electricity, the total gain is 0.042. ITER should then produce an increase of the gain by a factor only 7.4. It can be estimated that at least the same increase of gain is possible with the JET facility, if a number of additional neutral beam injectors were added. This would cost very much less than the projected ITER project cost and could be achieved in a much shorter time. However, this would be neutral beam fusion (Hora 2000, 2004) and contradict the Spitzer theorem of 1951.

The modified fast igniter (Nuckolls & Wood 2002) has still the disadvantage that the generation of the 5 MeV electron beams needs the interaction of a 10 PW-ps laser pulse with a plasma of very high (thousand times solid state) pre-compressed plasma. Then the electron beam ignites the voluminous low density DT fuel to produce 100 MJ fusion energy. This is the step to fulfil the initial dream that laser pulses may result in controlled ignition of virtually uncompressed solid DT fuel with very high gain.

A further step forward without any very high compression of plasma is to use space charge neutral ion beams instead of the relativistic electron beam as will be shown in the following section in order to completely fulfil the initial visions of Nuckolls (2005), with a plane geometry laser ignition of solid DT with PW-ps laser pulses.

EFFECT OF LASER DRIVEN PLASMA BLOCKS WITH VERY HIGH DT CURRENT DENSITIES

The following is a combination of the fast igniter concepts for laser fusion (Tabak et al. 1994) with the initial vision of Nuckolls (2005), in view of the recent development of petawatt-picosecond laser pulses. We underline the new aspects in this development, focussing on the fact that a new effect was found with the most anomalous measurements resulting from the interaction of laser pulses with a few TW-ps laser pulses (Sauerbrey 1996, Zhang et al. 1998, Badziak et al. 1999). Usually, these pulses produced extreme relativistic effects such as 100 MeV electrons, GeV highly charged heavy ions, extreme X-ray and gamma ray bursts with subsequent nuclear transmutations by the nuclear photo effect, pair production, and so on (Cowan et al. 1999). In strong contrast to this, the anomalous measurements showed very low X-ray emission (Zhang et al. 1998), very low ion energies (Badziak et al. 1999) and a rather transparent plane geometry plasma acceleration (Sauerbrey 1996). This could be combined with early numerical computations carried out around 1978 in Australia (Hora 1991) to explain these phenomena as a nonlinear force driven plasma block generation due to the avoidance of relativistic self- focussing by suppression of pre-pulses with extremely high contrast ratios (Hora et al. 2002, Hora 2003, Hora et al. 2005, Badziak et al. 2005).

We have first to return to the initial vision of Nuckolls (2005) as to whether irradiation of solid DT without pre-compression could result in ignition of a thermonuclear burn, or flame propagation. It has to be noted that the electron beam scheme of Nuckolls & Wood (2002) still needs very high plasma compression for generating the special electron currents and even the controlled fusion reaction in the large volume of DT of only 12 times solid state density needed the support of the highly compressed part of the fuel. We are aiming to use the ultra-intense ion beam following the skin-layer effect to avoid the requirement for very high compression.

Equivalent to laser irradiation, it was considered that electron beam irradiation or irradiation by a beam of DT could be used for the flame ignition (Bobin 1974). It turned out that a DT ion beam current density under optimized conditions of

$$\mathrm{j} > \mathrm{j}^* = 10^{10}\ \mathrm{A\,cm^{-2}} \tag{1}$$

was necessary and an energy flux density E given below was required.

$$\mathrm{E} > \mathrm{E}^* = 10^{8}\ \mathrm{J\,cm^{-2}} \tag{2}$$

The condition (1) was many orders of magnitude beyond any particle beam technology and the condition (2) also was very extreme. It should be mentioned that by evaluation of the fusion detonation wave at spark ignition (Hora et al. 1998), the ignited core produced a value of $\mathrm{E} = 1.62 \times 10^9\ \mathrm{J\,cm^{-2}}$ for ignition of the high density low temperature outer DT shell. A correction of E^* in (2) to about ten times lower values may be possible (Hora 1983) if the interpenetration of the energetic particles into the low temperature fuel is considered, if the anomalous resistivity is included as expressed by the quantum correction of the classical collision frequency, and if the inhibition of the thermal conductivity is taken into account as given by the double layer between the hot and cold areas.

The fast ignitor scheme (Tabak et al. 1994) for laser fusion where the fuel is compressed to several thousand times the solid state density with ns laser pulses and the missing temperature in the centre for spark ignition was assumed to be provided by a ps-PW laser pulse, led to the development of these pulses. When studying the interaction of ps laser pulses of TW and higher power, the above-mentioned numerous relativistic effects (Cowan et al. 1999) were observed. If, however, the relativistic self focussing was avoided by suppressing any laser prepulse (high contrast ratio), the plane geometry of interaction within the *skin layer* of the plasma surface produced two plasma blocks. This is by nonlinear (ponderomotive) forces (SLA, skin layer plasma block acceleration by the nonlinear force), one moving with low sidewise expansion against the laser light and the other into the plasma (Figure 1), as expected

from computations carried out prior to 1980, (Figure 2). This was first analysed from ion emission (Badziak et al. 1999, Hora et al. 2002) and confirmed in all details, both experimentally (Badziak et al. 2004) and numerically (Badziak et al. 2005).

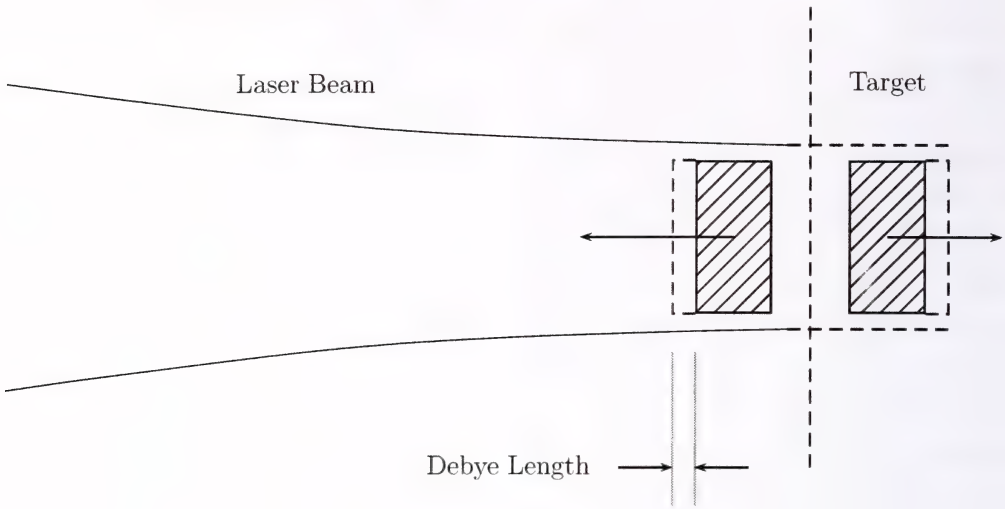

Figure 1. Fusion scheme where a laser beam irradiates solid DT producing a block of plasma moving against the laser light and another block moving into the target. Ignition requires extremely high DT current densities and energy fluxes of the blocks, equations (1) and (2).

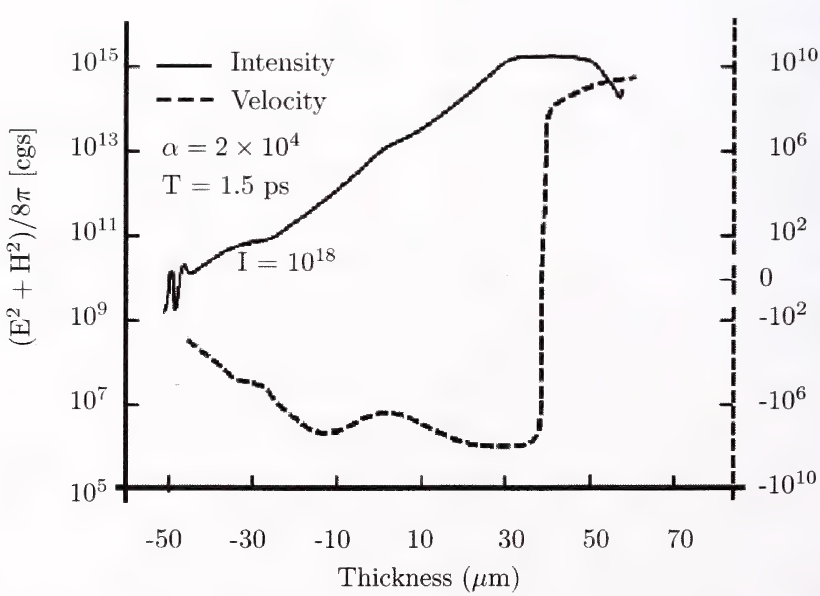

Figure 2. Generation of blocks of deuterium plasma moving against the neodymium glass laser light (positive velocities, v, to the right) and moving into the plasma interior (negative velocities) produced upon irradiation by a neodymium glass laser of 10^{18} W cm^{-2} intensity onto an initially 100 eV hot and 100 μm thick bi-Rayleigh profile (Hora 1991) with minimum internal reflection. The electromagnetic energy density $(\mathbf{E}^2+\mathbf{H}^2)/(8\pi)$ is shown at the same time of 1.5 ps after beginning constant irradiation (Cang et al. 2005).

The suppression of the self-focussing was indirectly confirmed (Hora et al. 2002) from the measured intensity independence of the accelerated ion numbers (Badziak et al. 1999). The suppression of the self-focussing channel (Hora 1975, 1991, Häuser et al. 1992) was ingeniously measured by Zhang et al. (1998) where TW-100 fs laser pulses were clean with a contrast ratio of 10^8; the need for a pre-pulse generated plasma plume for the relativistic self-focussing was demonstrated by detecting the emitted X-rays changing from very low values without self-focussing into very high values if a femptosecond pre-pulse was irradiated at least 70 ps before the main pulse.

It is very important to underline the fact that SLA-plasma-block acceleration was observed previously, without the later realized connections, by Sauerbrey (1996), confirming in retrospect that his 350 fs TW laser pulses were sufficiently clean. The pulses were produced by the Schäfer-method, amplifying 350 fs dye-laser-pulses through an activated KrF laser medium (Schäfer 1986) without the need for gratings or pulse compression as with Mourou's chirped pulse amplification CPA method (Mourou & Tashima 2002). Sauerbrey (1996) measured an acceleration, A, in a carbon plasma front moving against the laser by the Doppler effect, produced by a 350 fs TW KrF laser pulse at 3.5×10^{17} W cm^{-2} as follows:

$$A_{exp} = 10^{20} \text{ cm s}^{-2} \tag{3}$$

This corresponds to an electric field $\mathbf{E}^2 = 2.9 \times 10^{15}$ erg cm^{-3} and a density, $n_i m_i$, of the accelerated plasma layer of 5.4×10^{-3} g cm^{-3} at the critcal density $n_i = 1.6 \times 10^{21}$ cm^{-3} for C^{6+} ions. The nonlinear force for the simplified plane geometry (Hora 1991) is given in (4).

$$\begin{aligned} f_{NL} &= - (\partial/\partial x)\ (\mathbf{E}^2 + \mathbf{H}^2)/(8\pi) \\ &= n_i m_i A \\ &= -(1/16\pi)(\omega_p/\omega)^2(\partial/\partial x)\ \mathbf{E}^2 \end{aligned} \tag{4}$$

Assuming for simplification $\partial x = \Delta x = 10\,\mu m$ and a swelling of $S = 2$ (the experiments of Badziak et al. (2004, 2005, 2006) for ps pulses resulted in $S = 3.5$), we find the theoretical value given in (5).

$$A_{NL} = 1.06 \times 10^{20} \text{ cm s}^{-2} \tag{5}$$

Applying this result to the accelerated plasma blocks of DT with a critical density at $n_e = 10^{21}$ cm^{-3} and an ion velocity above 10^8 cm s^{-1} shows that the plasma blocks have an ion current density above 10^{10} A cm^{-2}, therefore fulfilling condition (1) for flame propagation. A very detail numerical confirmation of this fact using the genuine two-fluid model has been provided (Badziak et al. 2005, Cang et al. 2005, Glowacz et al. 2006).

ENERGY FLUX DENSITY FOR FUSION FLAME PROPAGATION

We now discuss how condition (2) could be fulfilled with ps laser pulses of TW power or several PW by defocussing to large areas and interacting with the DT in order to produce moderate ion energies, since the optimized DT fusion cross sections require 80 keV only. Experiments (Badziak et al. 1999, 2004, 2005) provided E values for (2) of nearly 10^6 J cm^{-2}.

For the compressing block, the whole maximum quiver energy of the electron is converted into translation energy of the ions. For the DT interaction, use of an oscillation energy of 80 keV for the resonance maximum of the DT reaction may not necessarily be the best choice. Since this is close to the relativistic threshold intensity I_{rel} we have to use the general quiver energy (Hora 1991)

$$\varepsilon_{osc} = m_o c^2\ [(1 + 3SI_{vac}/I_{rel})^{1/2} - 1] \tag{6}$$

where the maximum intensity $I_{max} = SI_{vac}$ due to the dielectric swelling near the critical density is expressed by the factor S with the laser intensity I_{vac} in vacuum at the target surface.

For the general analysis we have to be flexible about the chosen values of the applied maximum (dielectrically swelled) oscillation energy ε_{osc} into the translation DT ion energy ε_{trans} in adjustment of fusion cross sections. We further leave open the value of the energy flux density $E^* = I_{vac}/\tau_L$ for reaction condition (2) [possibly even a lower value depending on future research on interpenetration mechanisms (Hora 1983)] to find the correct value of E^* where the laser pulse duration τ_L will have to be in the range

of ps. According to numerical studies (Cang et al. 2005, Badziak et al. 2005, Glowacz 2006), in agreement with estimations, this value could well be a few ps. From (7)

$$I_{vac} = E^*/\tau_L \tag{7}$$

we arrive at the function for the laser wave length given in (8) where m_o is the rest mass of the electron.

$$\lambda(\varepsilon_{trans}, E^*, \tau_L, S) = [\tau_L I^*_{rel}/3SE^*]^{1/2} \{[(\varepsilon_{trans}/m_o c^2) + 1]^2 - 1\}^{1/2} \tag{8}$$

Using as a special case $\tau_L = 3\,\text{ps}$, $E^* = 2 \times 10^7\ \text{J cm}^{-2}$, $\varepsilon_{trans} = 80\,\text{keV}$, we arrive at (9).

$$\lambda = 0.516/S^{1/2}\,\mu\text{m} \tag{9}$$

The nonlinear force driven two-block skin layer interaction model (Figure 1) works for swelling, S, considerably larger than 1, as was the case automatically from detailed analysis of the measurements (Hora 2003) with S = 3. The lowest possible case with S = 1 is that without any dielectric swelling where the whole laser pulse energy is transferred, as in the simple case of radiation pressure to the (nonlinear-force dominated, nearly collisionless) absorbing plasma. We conclude that the condition (2) could well be fulfilled for the ignition of uncompressed solid DT fuel when applying shorter laser wave length than that of the neodymium glass laser; this is well in reach of present technology. For the pessimistic case of Bobin (1974), the numerical factor in (9) is 0.105, such that with S = 1 just the borderline of higher harmonics CPA (Mourou & Tashima 2002) or of excimer lasers (Schäfer 1986) would be covered. Further research on lower values of E* and numerical studies for slightly longer laser pulses may further relax the conditions, and longer laser wave lengths would be possible. Figure 3 shows the dependence of the necessary laser wave length for a pulse length of 3 ps and swelling S = 1 which one needs for a desired ion translative energy in multiples of m_oc^2, if the threshold E* is given. Maybe there is a narrow gap for successful conditions.

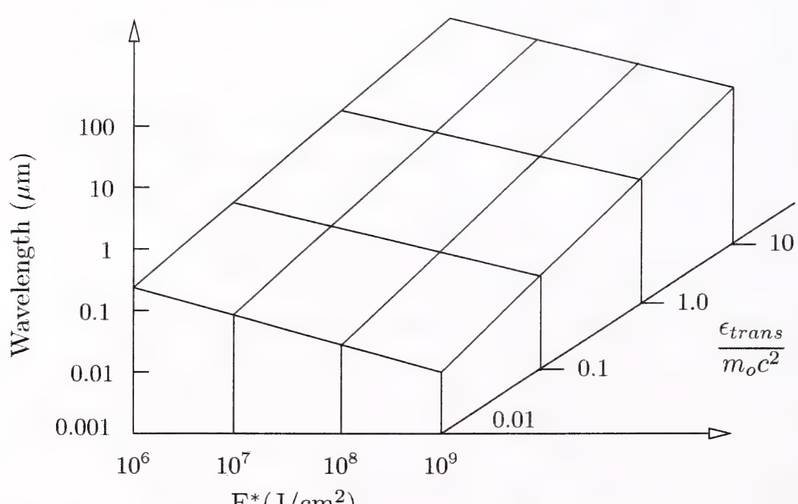

Figure 3. Relation between the laser wave length, aimed ion energy ε_{trans} in multiples of m_oc^2 and the necessary energy flux density for ignition of uncompressed DT following (8) for S = 1 and a laser pulse duration of 3 ps.

DISCUSSION

To produce energy at five times lower cost than all the existing energy sources on earth is potentially achievable if the laser could ignite solid state DT without the complicated precompression step. It is remarkable that Nuckolls & Wood (2002) developed the option of the fast igniter where very intense 5 MeV electrons would ignite large quantities of nearly solid state (or moderately compressed) DT and where some 10 kJ of laser energy produces more than 100 MJ of fusion energy. It can be assumed that this ignition scheme involves controlled laser fusion processes quite differently to uncontrolled fusion reactions. A similar scheme may be reached with nonlinear force driven skin layer acceleration SLA plasma blocks (Hora 2002). The necessary condition (1) for $10^{11}\,\mathrm{A\,cm^{-2}}$ and higher DT ion current densities for this have been verified (Hora et al. 2002, Badziak et al. 2005) for optimum ion energies of 80 keV. For condition (2), the possibilities seem to be in reach since the value E^* will be considerably reduced in view of modifications that have not yet been fully explored. The final question is whether the necessary laser intensities of 10^{17} to $10^{18}\,\mathrm{W\,cm^{-2}}$ of few ps duration provide comparable conditions for igniting the fusion flame in a way similar to radiation ignition (Nuckolls 2005), which refer to uncontrolled reactions with similar intensities of Planck radiation (11 million K).

With several preliminary estimations concerning fusion, apart from solid experimental and theoretically based results on plasma block generation, the present study may provide the framework for further evaluation of Particle in Cell (PIC) computation results for generation of plasma blocks (pistons) covering conditions (1) and (2) (Esirkepov et al. 2004). We must find out how to avoid relativistic self-focussing and how to optimise DT ion energies for the fusion flame. Our present position from the side of sub-relativisitc conditions may be an alternative approach leading to a very simplified low cost laser fusion reactor.

If this laser-plasma block controlled ignition (LABIG) scheme becomes a serious method of producing energy at very low cost, nonproliferation problems associated with uranium fission would be greatly reduced (Hora 2002). The benefits in reducing global warming would be much greater than the risks of a suggested increase in the number of fission reactors. Unlike the finite supply of uranium, the availability of hydrogen and its isotopes is essentially unlimited.

The problems to be clarified are the new theoretical aspects of the interpenetration process for Bobin's (1974) fusion flame and techniques for producing sufficiently thick highly directed and low temperature plasma blocks by the skin layer effect. The use of radially driven layers with shrinking width and increasing thickness are currently being discussed (Badziak et al. 2006).

CONCLUSIONS

Interaction of TW-ps laser pulses with plasma results in a skin layer mechanism for nonlinear (ponderomotive) force driven two dimensional plasma blocks (pistons). This mechanism relies on a high contrast ratio for suppression of relativistic self-focussing. Space charge neutral plasma blocks are obtained with ion current densities larger than $10^{10}\,\mathrm{A\,cm^{-2}}$. Using ions in the MeV range results in 1000 times higher proton or DT current densities than the proposed proton fast igniter requires (Roth et al. 2005). This should result in better conditions of this fast ignitor scheme. The ballistic focusing of the generated plasma blocks and then short-time thermal expansion increases their thickness but maintains high ion current densities. As shown here, this approach then provides conditions that are very favourable for efficient fast ignition of a fusion target. If successful, this approach to fast ignition could significantly simplify operation of an IFE plant, leading to very attractive energy production costs.

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Thesis Abstract: The Australian Stellate-haired Rhamnaceae: a Systematic Study of the Tribe Pomaderreae

JÜRGEN KELLERMANN

Abstract of a Thesis submitted for the Degree of Doctor of Philosophy, University of Melbourne, Victoria, 2007

Rhamnaceae Juss. is well represented in Australia with about 240 species. Over 90% of these belong to Pomaderreae Reissek ex Endl., the second largest tribe of Rhamnaceae, which is endemic to Australia and New Zealand. The defining characters of the tribe are the presence of stellate hairs on stems, leaves and/or flowers and schizocarpic capsular fruits. Individual fruitlets are indehiscent or release the seed through an opening or slit.

Pomaderreae currently consist of seven genera in Australia, of which only one (*Pomaderris* Labill.) extends to New Zealand. The limits of the genera were confused by many botanists over the last 150 years, with two to seven genera being accepted over time. This thesis aims to clarify the generic limits and resolve the position of several atypical species.

Parsimony analyses of two DNA regions, the Internal Transcribed Spacer (ITS) from nuclear DNA and the *trn*L-F region from chloroplast DNA, were conducted separately and combined. The combined data-set contained 69 taxa of Pomaderreae; it was analysed with successive weighting to down weight base positions that changed excessively and resulted in a well-supported phylogeny. Morphological data was mapped on to the cladogram to explore the variation of characters and to find key synapomorphies for the clades.

The results of the different analyses were generally congruent, but the arrangement of the clades to one another was not resolved satisfactorily and the position of some species changed between analyses. The ITS phylogeny was well-resolved, in contrast to the *trn*L-F analysis, which contained only few clades and many polytomies. Long homoplasious indels hampered the *trn*L-F analysis and resulted in seemingly unrelated species being grouped together.

Pomaderreae is monophyletic, which corroborates findings by Richardson et al. (2000a, 2000b) and Fay et al. (2001). Five main genera of Pomaderreae, *Pomaderris*, *Siegfriedia* C.A. Gardner, *Spyridium* Fenzl, *Stenanthemum* Reissek and *Trymalium* Fenzl, are confirmed, but some name changes are needed to achieve a classification with monophyletic genera: the Victorian species of *Trymalium* and *Cryptandra waterhousei* F. Muell. should be transferred to *Spyridium*; *Blackallia connata* C.A. Gardner needs to be subsumed in *Cryptandra* and the genus *Blackallia* C.A. Gardner has to be restricted to *B. biloba* C.A. Gardner. Three new genera are suggested. The first should include the four species of the 'Bilocular Clade', a group of species previously thought to be unrelated. The second genus would be monotypic containing *Stenanthemum gracilipes* Diels. The last new genus would consist of two other species so far included in *Stenanthemum*.

The current results do not support a split of *Cryptandra*, although a number of morphologically distinct species or groups of species have been suggested by others to warrant generic rank. Most of these unusual species are part of a 'basal' grade that is separated from a clade containing mostly 'typical' species of *Cryptandra sensu* Thiele & West (2004), however, resolution within the *Cryptandra* clade is limited and only few nodes receive statistical support.

The indumentum on leaves of selected species of Pomaderreae was examined with Scanning Electron Microscopy to assess the variation of hair types and their distribution. Trichomes are quite variable and range from simple hairs to fasciculate or dendroid multiradiate hairs. The indumentum in some taxa, such as *Stenantemum*, the three new genera, or *Cryptandra*, seems to be more constant and might provide synapomorphies for certain clades or groups of species in the future.

Cladistic biogeographic analysis of the tribe, using the strict consensus tree of the combined analysis of ITS and *trn*L-F sequences, has found general patterns of relationships of the areas inhabited by species of Pomaderreae, which is in agreement with patterns found in other groups of plants and animals in Australia and New Zealand. The summary cladogram indicates three main areas: the tropical North, Western Australia and south-eastern Australia (including New Zealand). The hypothesis is proposed that Pomaderreae is a relatively old group of plants and that the origin of the main lineages within the tribe can be explained by vicariance.

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Thesis Abstract: A 2000 Year Record of Environmental Change from Tocal Homestead Lagoon, Eastern Australia

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Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
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A high-resolution sedimentary record from Tocal Homestead Lagoon, in the lower Hunter valley of eastern Australia, has provided detailed information on environmental change during the last *c.* 2000 years. Twenty-four cores were retrieved from the lake. These have been correlated using magnetic susceptibility measurements, allowing the construction of a basin-wide magneto-stratigraphy. The core with the longest, most complete and the highest resolution record (core TCA9b) was sub-sampled and analysed for a suite of physical, magnetic and chemical properties. The lake sediments have been precisely and accurately dated using a range of independent methods providing arguably the most detailed, continuous record of late Holocene environmental change on the Australian continent. Radiocarbon, palaeomagnetic and radiometric dating have been used to identify the sedimentary horizon of first European contact in the early 19th century AD. This has allowed a detailed record of catchment-wide soil loss for the period *c.* 1820 to 1998 AD to be obtained, providing a rare opportunity to examine the timing and magnitude of the landscape disturbance that accompanied European settlement in the 19th century. In addition, insights into the state of the pre-impact environment during the last *c.* 2000 years have also been gained, providing much needed information on late Holocene environmental change and pre-European human impacts.

The Tocal Homestead Lagoon record has shown that periods of contrasting climatic conditions prevailed during the late Holocene in eastern Australia. These environmental shifts have, so far, not been recorded in any of the pollen-based palaeoenvironmental records from the region. In particular, the Tocal record has provided some evidence of a prolonged warm period after *c.* 900 AD, broadly coincident with the Medieval Warm Period. The lake sediments have also supplied indirect evidence of the chronology of Aboriginal occupation at the site. Burning of the immediate catchment has taken place regularly since *c.* 150 BC. This is in agreement with most fossil charcoal records in the region, which show that regular firing of the environment has occurred during the last several millennia. More explicit evidence of Aboriginal occupation comes from the lake sediment chemistry, with the concentration of P increasing above background levels from *c.* 800 AD, roughly 1000 years before European settlement in the region.

By the time the first European had entered the catchment, P levels had already doubled above the site's pre-800 AD, background level. In the absence of any other plausible explanation, this has been cautiously interpreted as a record of pre-European human activity within the Tocal catchment.

The mean rate of catchment-wide soil loss for the *c.* 2000 years before the arrival of Europeans was $18\,\mathrm{t\,km^{-2}\,a^{-1}}$. This may be contrasted with the mean rate of erosion experienced under European land use of $228\,\mathrm{t\,km^{-2}\,a^{-1}}$, an increase of more than an order of magnitude. Although this mean rate for the post-settlement period is comparable to modern rates of catchment sediment yield in eastern Australia, it masks periods of much greater denudation.

The arrival of Europeans at Tocal is clearly recorded in the lake sediments as a pulse of topsoil-dominated material, which marked a spectacular rise in erosion to $638\,\mathrm{t\,km^{-2}\,a^{-1}}$, more than 200 times higher than the rate at which soils were being eroded in the preceding four centuries. Truncated A-horizons and compacted soil profiles in the catchment today provide modern records of this past denudation. The catchment's response to the arrival of Europeans, the clearing of land for farming and the impact of thousands of hard-hoofed animals in the catchment was both swift and intense. In contrast, the pollen record for the period immediately before and after European settlement shows little variation, which has important implications for our understanding of vegetation response to human impacts in the Australian environment.

Although the initial shock of European impact resulted in a dramatic increase in erosion, the greatest rates of catchment-wide soil loss at Tocal took place during periods of intense cattle ranching at the beginning of the 20th century. Earlier, when agriculture at the site was crop-dominated, the catchment appears to have been more stable and erosion less severe. Lower rates of erosion have been recorded in the last decade at Tocal, which may represent the impact of more sustainable farming practices. This pattern is somewhat different to that recorded in other long-term sedimentation records in eastern Australia, which show that the greatest erosion rates immediately followed European settlement.

Decadal-scale climatic variations appear to have had little direct influence on the history of erosion, although there is good evidence that extreme climatic conditions may have been responsible for amplifying the already severe impacts of intensive land use. This may be in part due to the dominant role of land use in controlling erosion in the historic period. However, the observed cycles of drought and flood in the region in the decades before European settlement in *c.* 1820 appear to have had no impact on soil erosion either. It appears that the pre-European environment may have had some level of resilience to short-term climatic fluctuations and Aboriginal land use. If some level of equilibrium existed in the pre-European environment, then it was both easily and rapidly disturbed and any resilience such systems may have had to minor climatic fluctuations appears to have been incapable of coping with the environmental changes that accompanied the arrival of Europeans in Australia.

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Thesis Abstract: The Postcranial Skeleton of Temnospondyls (Tetrapoda: Temnospondyli)

KAT PAWLEY

Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
La Trobe University, Victoria, 2006

Temnospondyls are large extinct fossil tetrapods, superficially resembling crocodiles in their general size, appearance and lifestyle. Temnospondyls are a group of early tetrapods, the oldest fossils are more than 340 million years old, and they existed for more than 200 million years. This doctoral thesis examined the postcranial skeleton of temnospondyls and its evolutionary history and diversification. Standard taxonomic techniques were used to distinguish between the types of variation observed in the postcranial skeleton and for phylogenetic analysis. The thesis consists of a series of published articles, three describing the postcranial skeletons of various temnospondyls, and three summary articles, all with extensive illustrations.

To provide data, the postcranial skeletons of three temnospondyl taxa were described. The articulated postcranial skeleton of a basal stereospondyl (rhinesuchid) is immature, and paedomorphism of the postcranial skeleton in stereospondyls is discussed. The robust appendicular skeleton of *Eryops megacephalus* is plesiomorphic, well-ossified, and terrestrially adapted. The paedomorphic postcranial skeleton of *Trimerorhachis insignis* is plesiomorphic, and secondarily aquatic; the description includes growth stages.

This study found that extensive morphogenetic variation is present in the postcranial skeleton of temnospondyls. Many phylogenetically significant characteristics develop with morphogenesis, they may be absent in early growth stages, and may never develop even in the largest growth stages of taxa with paedomorphic postcranial skeletons. Consequently, assessment of the presence or absence of a phylogenetically significant characteristic in any taxon may be dependant on the morphogenetic stage of the specimen examined. This finding has major implications for the phylogenetic analysis of temnospondyls and other early tetrapods. An overview of phylogenetic variation in the postcranial skeleton is presented, including a large phylogenetic analysis of the Temnospondyli. The most primitive temnospondyls possess fully ossified postcranial skeletons, well adapted for terrestrial locomotion, but some of the derived clades of temnospondyls have paedomorphic postcranial skeletons and are exclusively aquatic.

For the first time, the postcranial skeleton of temnospondyls is comprehensively compared with that of other early tetrapods in the largest phylogenetic analysis to date, resulting in the unexpected discovery that temnospondyls are most closely related to the ancestors of amniotes. The Temnospondyli plus Neospondyli (Seymouriamorpha plus Cotylosauria plus Lepospondyli) forms a large new clade, the Terrapoda, defined by the presence of many derived synapomorphies. Some of the cranial synapomorphies of the Terrapoda are most likely related to improvements in hearing. The postcranial synapomorphies indicate that the Terrapoda are the first vertebrates to have evolved limbs that are well adapted for terrestrial locomotion. The Terrapoda are the first truly terrestrial vertebrates; their postcranial adaptations facilitated their colonisation of the land and consequent phylogenetic radiation during the early Carboniferous.

Both analyses incorporate characters from previous analyses and many new postcranial characters. The results of the phylogenetic analyses are statistically more parsimonious than previous analyses and have much lower levels of homoplasy. Comparative analyses indicate that the distinctive results are most likely due to the increased use of characters pertaining to temnospondyls, increased use of postcranial

characters, and differentiation between sources of morphological variation to minimise morphogenetic and phenotypic variation and elucidate true phylogenetic signal.

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The complete thesis is online at:
`http:www.lib.latrobe.edu.au./thesis/public/adt-LTU20061124.124055/index.html`

Thesis Abstract: Identification of Novel Genetic Regulators of Breast Cancer Metastasis

BEDRICH ECKHARDT

Abstract of a Thesis submitted for the Degree of Doctor of Philosophy, University of Melbourne, Victoria, 2006

The majority of deaths due to breast cancer result from the formation of secondary tumours (metastasis) that arise in distant organs such as lymph nodes, lung and bone. Metastatic spread to these organs leads to debilitating complications, such as respiratory problems, spinal cord compression, bone pain and fractures. Current therapies are palliative, aiming to relieve the symptoms caused by metastatic growth. To achieve curative therapies, a better understanding of the genetics that underlie the process of metastasis is required.

To this end, a unique mouse model of spontaneous breast cancer metastasis to multiple sites was characterized both at the phenotypic and genotypic levels. Using a novel real time quantitative PCR assay of metastatic burden, several mouse mammary tumour lines were characterized for their ability to spontaneously metastasise to various tissues. Based on this assay, the tumour lines were categorized as non-metastatic (67NR), weakly metastatic (4TO7, 168FARN and 66cl4) and highly metastatic (4T1.2 and 4T1.13). In conjunction, functional assays that mimic the individual events of metastatic progression revealed that highly metastatic tumour lines were more adhesive, migratory and invasive compared to their weaker metastatic counterparts.

Each metastatic tumour was array-profiled against the non-metastatic 67NR to elucidate genes associated with metastasis in this model. Gene ontology analysis of the array data revealed that genes involved in adhesion, motility and invasion were inherently altered between weakly and highly metastatic tumours. Further, the genetic differences between highly and weakly metastatic mouse tumours were able to segregate a cohort of human breast cancer patients into 'early' and 'late' metastasis categories.

In highly metastatic tumours, a significant proportion of extracellular matrix (ECM) genes were over-expressed. An ECM gene, POEM/nephronectin, was identified and evaluated for a functional role in metastasis. Reduction of POEM expression by stable RNA interference in the highly metastatic 4T1.2 tumour line impaired metastasis to lung, bone and kidney. A second gene, bone morphogenic protein-4 (BMP-4), was identified with minimal expression in 4T1.2 tumours. Restoration of BMP-4 expression in 4T1.2 tumours inhibited metastasis and dramatically improved the survival of mice bearing these tumours. These studies implicate a causal role for POEM and BMP-4 in the progression of breast cancer. Further characterisation of these genes will aid in the development of more specific and effective therapies for metastatic breast cancer.

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Thesis Abstract: Behavioural Ecology of the Bobuck (Trichosurus cunninghami)

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Abstract of a Thesis submitted for the Degree of Doctor of Philosophy,
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This thesis demonstrates the profound influence that patterns of resource distribution and abundance can have on the behavioural ecology of a marsupial. I studied two neighbouring populations of bobucks, *Trichosurus cunninghami*, within a fragmented forest landscape in the Strathbogie Ranges, south-eastern Australia. There were numerous marked differences between the 'forest population', which inhabited a forest patch and the 'roadside population' which occurred in linear roadside vegetation.

The forest population was socially monogamous; the adult sex ratio was at parity and there were no significant differences in the number of den-trees used by adult females and males or in their home range sizes. Pair-members had strongly overlapping home ranges, shared den-trees and remained close to one another during their nocturnal activity period. Pair-bonds ended only as a result of the death of one pair-member. Two-thirds of young were sired by the female's social partner and most males sired one young per year. There was a significantly male-biased offspring sex ratio and all males that were born at this site and survived to three years of age dispersed; all females were philopatric. Females inherited some of their mothers' den-trees and, as adults, established home ranges that overlapped substantially with their mothers' ranges. Patterns of genetic relatedness indicated that all adult males in the forest population were immigrants.

In contrast, the roadside population was polygynous; the adult sex ratio was female-biased and male home ranges were significantly larger than those of females. Each male's home range overlapped with those of two or three females, and males used significantly more den-trees than females. There was no bias in offspring sex ratio; genetic data revealed that there was no sex-bias in dispersal, and that males sired multiple young per year. Both of the key resources for bobucks (den-trees and silver wattle, *Acacia dealbata*, the main dietary item) occurred at significantly higher density at the roadside site, and were located in close proximity to one another. Conversely, these resources were widely separated at the forest site. There were no significant differences in the number of den-trees or silver wattle trees located within the home ranges of females at the two sites, but females at the forest site had home ranges approximately three times the size of those of roadside females.

At the forest site, patterns of den-use and den-sharing, and the relative location of den-trees and preferred foraging areas, suggested that suitable den-trees located close to food trees were limiting. To test this hypothesis, I artificially supplemented hollow availability by installing nestboxes within the core foraging range of each adult female in the forest population. In contrast to the findings of other studies, the nestboxes were rapidly colonised by bobucks, indicating that if natural hollows were available closer to food resources, as they were at the roadside site, they would almost certainly be used.

My study establishes that bobucks have a variable mating system, governed by the availability and distribution of key resources. Specifically, where resources were sparse and widely distributed, females had large home ranges, and males were constrained to social monogamy by the spatial distribution of females.

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